DESIGN SUGGESTIONS FOR GLASS BUILDING FAÇADES UTILIZED WITH ALGAE ENERGY SOURCES

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Abstract— Highly-intensified daylight distribution through glass-wall may distract the clear definitions of building parts. Besides, building parts very often are identified with the functions designed within some illumination, opacity and transparency values.On the other hand, currently, there has been a growing interest in energy issues, and the energy problem has occurred in the building. Algae Façade systemproducing energy sources through the building componentsis being appeared as one of new efficient alternatives toresolve the problem, and the proposed system will be able to serve for enhancing the user health and handling sensitivity of environmental change. By utilizing the algae, it is possible to produce environmentally friendlyenergy resources and utilize an integrative system giving a color change to the building. The integrative algal façade connecting LED lamps in the enclosed photo-bioreactor system is currently being developed as a cutting-edge technology to try for growth of color expression towards algal glass enclosures, and this way will give design directions for various building elevations beyond the originally simple green enclosures.

Index Terms—Glazing, Daylighting, Spatial Organization, Algae Façade, Glass Enclosures, Building Design Suggestions.

I. INTRODUCTION

In most cases, design principles in architecture derive from particular circumstances of the design problem. Nevertheless, it can be observed that these circumstances may end up the similar or repeated design configurations. These similarities, in fact, introduce a way of thinking with typology in architecture. This suggests the similarities as necessary tools that may be used to refine the repeating design schemes that in different circumstances. This refinement will suggest prototypes that describes the roof forms underlying repeated schemes. This paper will present an attempt to investigate a prototype, in particular glass buildings that will clarify the interpretation of root form. [1]

This paper will consist of two main parts: one is review on definitions of typology and prototype and a short argument about how to conceive them in design theory process; and case studies glass use in architecture with images and plans. In the case studies part, the historical context and symbolic content of those buildings will be neglected, but root form of these glass buildings will be examined in an evolutionary approach. Selected photographical illustrations and plans of them will display some clues about the root order, initiated through material features of glass and functional organization. [2]

This study can be seen as a part of the approach that seek the way in which environmental conditions of building are integrated with architectural design. As daylight distribution is an environmental condition of which spatial implications can be most explicitly defined, in this study it will be more focused on than other environmental conditions. Glass enclosure is the object of this focus, as it provides a ground for questioning the impact of materiality and daylight distribution on identifying an architectural space.

The main objective of this study is questioning how some repeated rules, patterns of functioning building parts are affected from daylight distribution in glass buildings, and how these patterns can be initialized within architectural design studies.

II. TYPE AND PROTOTYPE OF GLASS FAÇADE

A. Theory of Type and Prototype in Architecture

In the second half of the Twentieth Century, architectural critiques suggested new mechanisms to interpret the built form. Typological interpretation has been argued as one of these mechanisms. It suggests defining built form on the basis of type, basically as a conceptual construction that distinguishes similar from dissimilar so that something is identified within certain categories. On the basis of that simple definition of type, typological interpretations in architecture are based on a priori forms or orders in perceiver's mind, archetypes. Archetypes are defined as psychological models that are conceived within experiences of space. Despite the fundamental similarity between type and archetype, type can be more defined as abstract scheme of the root order that can be conceived in a built form, which are elaborated or shaped with social constructions, whereas archetype involves with similarities recognized by sub-conscious perception.

B. Structural Relations and Prototype

The definition of type can be argued through space syntax theories, which seek the structural relations between built form and social relations. In the central argument of these theories, Bill Hillier investigates the way in which the logic behind the designed artifact is formulated as consisting of first, "objectives and rules that guide the material to be assembled for a well-defined purposes, and second as style that gives artifact a certain significance over practical needs".

[3] He conceives these two aspects as genotype and phenotype, as defining the former concept as abstract rules of relations that constitute the global system, while conceiving the forms explicitly realized onto those rules as phenotypes. In his definition, the genotype implies abstract rules underlying spatial forms rather than forms themselves. He considers then, genotype does not contain variations as much as phenotypes.

As the definition of type is liberated form symbolic content and formal–stylistic orders, it approximates the definition of genotype. [4] Conceiving type in such an abstract degree can enable to derive some beneficial arguments for design theories. In fact, as one can try to see the abstract rules and structural relations that present type or genotype in a particular model sample, another term should be recalled such as prototype.

C. Designing though Prototypes

Typological interpretation of built forms can guide to construct some design models. The principles that constitute a designed form are outcome of an integrated knowledge of what a designer explicitly present and what he/she has implicitly in mind, tacit knowledge. In design process, one way to accomplish in creativity can be provided by reflecting the tacit knowledge in the form of explicitly defined principles. In some of the arguments, typological thinking is seen as a tool to bring the tacit knowledge into the explicit principles. [5] Then, design is argued as constructing worlds by using the predetermined models in designer's mind by using the tacit and explicit knowledge of built environment. In this construction, types are suggested as references from which the rules are derived to bring forth the predetermined models.

In other words, types constitute base models to present some derivative rules that generate constructions. This notions addresses rules, derived from types as both underlying abstract principles of a creation and references that provide a ground for criticizing and testing the designed artifact.

III. FUNCTIONS OF GLASS FAÇADES

In the recent decades of twentieth century, leading tendency of constructing buildings by steel-and-glass, in pursuit of more lightweight appearance implies that glass buildings can be recognized as an architectural type. In fact, there are several aspects that trigger this tendency such as recent developments in construction and material technology. In this paper abstract rules and orders revealed and re-appreciated in many of glass buildings constructed will be investigated. In fact, most of these rules and orders derive from the materiality of glass itself. As these developments usually are very fact of building, they can influence the explicit knowledge of design. On the other hand, material implications of glass may also be illusionary that allow for the tacit knowledge of design.

A. Ecological Functions

The tendency of constructing the buildings made up of glass walls can be argued through some special functions of glass. New technological developments in glass material and glazing system enable to construct the exterior walls by all-glass, then it became possible to benefit from ecological function of glass to have a better environmental performance in the interiors. [6]

The ecological contribution of glass enclosure to the building can be sorted within two environmental conditions: (1) Double-skin glass providing thermal buffer zone by using solar energy, and (2) Daylight transmission quality of glass.The double skin glass walls with a wide cavity in between provide a great opportunity to overcome shortcomings of glass in terms of environmental performance. [7]

Table 1. Examples for Ecological Function of Glass

RWE Tower – Glass Tower in Essen

This 31 floor cylindrically shaped building has a double glass wall consisting of outer skin with 10 mm thick toughened glass and an inner skin with an insulating glass. In each section the air inlet is in one façade module at the bottom and the outlet is at the other module at the top, thus producing diagonal air-flow through the cavity. [8]
Commerzbank Tower – Frankfurt, Germany

The Commerzbank tower, at 300 meters tall, is the tallest naturally ventilated building in the world. A Norman Foster design. The goal was to create a revolutionary, environment and people friendly high-rise. There are some spaces designed utilizing ecological function of glass such as triangular atriums. Staircases, elevators, and utilities are located at the corners, leaving the building's core open as a continuous atrium and shaft for stack ventilation. [9]

The transparent glass can transmit the light in the radiation range from 315 nm to 3000 nm (this range recorded as 400 nm - 2500 nm in). The human eye is capable of detecting light in 380 - 780 nm intervals. Then, the range transmitted by glass comprises the ultraviolet radiation (315 - 380 nm), the visible range (380 - 780 nm) and the near infrared range (780 - 3000) nm. [9]

From the very early examples of glass architecture to the contemporary attempts, there are some features that can be grasped in spatial root order of glass buildings. These features display continuities in the

examples of glass architecture that have been constructed in different decades, but with some evolving ideas.

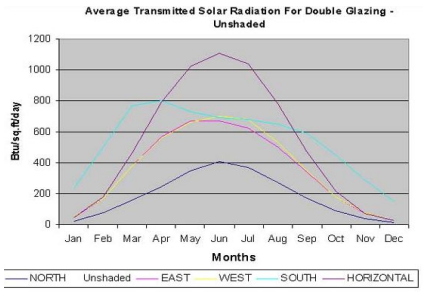
Table 2. Glass Types withVarious Transmission Coefficients

Float glass: clear glass (basic product).	
Body-tinted glass: It is a normal float-clear glass into whose melt colorants are added for tinting and solar-radiation absorption properties.	
Reflective glass: This is an ordinary float glass with a metallic coating to reduce solar heat.	
Low-e glass: Low-emission glass (Low-E) is a clear glass, it has a microscopically-thin coating of metal oxide, allowing the sun's heat and light to pass trough the glass into the building.	

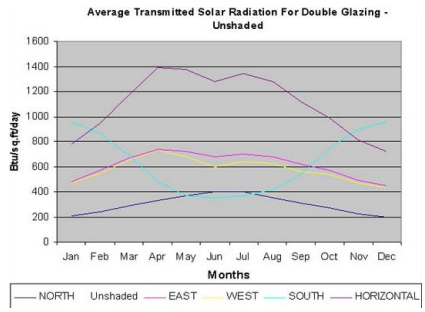
One thing that characterizes the spatial order of glass buildings can be recognized within new possibilities of construction technologies. Construction of all-glass buildings has been enabled when the structural skeleton of the building is liberated from the partition walls and exterior walls emancipated from the burden of load. Then, glass-wall has been introduced as a screen constructed with, usually, a separate frame. [10] In these buildings, advanced designs of reinforced or steel construction has been attempted to erect the buildings with a larger spans. Then, glass buildings often appeared as rectangular boxes of flexibly partitioned or un-partitioned big volumes. This can be conceived as formal properties of glass buildings that will appear as a category in investigating the prototypical patterns of the examples.

The transmission of light through glass walls can be argued one of the elements of space that affect occupants' perception of spatial order. Since, daylight enhances the material perception of surfaces, then definition of spatial order particularly in case of glass walls. This is again because of special material characteristics of glass that let to perceive both absence and presence, with transparency and reflectivity, of the boundaries with the play of light on its surface. This may implies the impact of light on to the ways in which inhabitants perceive the space and discriminate one space from another.

In fact, intensified distribution of daylight not only result in perceptual ambiguity but also provide a solar heating effect to the interiors, which can be beneficial for cold climates. Thus, besides the pursuit of visual integration of inside and outside, glass can be used to have the advantage of solar energy. This may encouraged the architects to use glass with large surfaces by designing the exterior walls as all-glass screens. All these material features of glass that affect the senses and spatial perception of interiors can be summarized as ecological function of glass, which provides another category for the case study.



(a) Weather Zone 7



(b) Weather Zone 1

Figure 1. Average Transmitted Solar Radiation for Double Glazing in Unshaded Condition

B. Psychological Function

Correlation between daylight illumination and productivity of inhabitants, correlation between transparency and the sense of privacy. It can also be argued through restorative effect of view from glass wall. There are some studies about the psychological effect of having a view through nature. Rachel Kaplan's study, 'The Nature of the View from Home', investigates how far having a view to outside through a transparent surface affect occupants restoratively particularly in workplaces. In most of the building types, she finds out that the big window has a very restorative effect.

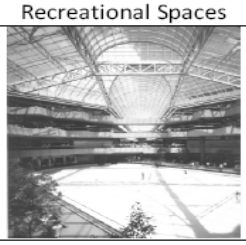
C. Structural-Spatial Function

As regards to the space-syntax theories, glass enclosures, particularly glass wall has displaced the critical relation between inside and outside. This critical relation involves with boundary imply the relationship between inhabitants and outsiders. It is argued that, the most significant factor that makes interior and exterior relation so important is the distinction between inside and outside itself, as inside and outside are formed with different sociological impulses. On the one hand, interiors are imprints of the shared roles in inhabitants' lives that implies well-defined correlation to the social categories, in the sense that "building interiors characteristically have more categorical differences between spaces, and in

general more definition of what can happen and where and who is related to whom else". The space outside the building, on the other hand, expresses a collective influence of social forces within less-defined social categories. [11]

The space outside the building expresses a collective influence of social forces within less-defined social categories. In this context, one can even argue that use of glass bring about some cultural consequences within integration of inside and outside. This way of questioning may refer to spatio-structural function of glass. Some studies that investigate reflections of glass-wall in social context can be re-comprehended within this approach. For example, the sociological explorations of Richard Sennett in his influential book The Conscience of Eye, in which he argues the integration of inside and outside implies unexpected cultural consequences can be seen as one of these.

Table 3. Pattern of Functioned & Designed Space

Atrium Voids	Public Halls
	
Recreational Spaces	**Semi-open Spaces**
	

These material implications glass, categorized in this study as three aspects, influence the way of perceiving the spatial integrity of the building. In fact, this gives designer some tools of destructing and freeing from hierarchy of spaces from interior to exterior. In most of the glass buildings, the patterns of these rules are reflected in a new kind of spatial order. Examining a group of buildings that consist of seminal examples from Modern and Contemporary architecture can reveal this spatial order as prototypical rules or patterns. The selected examples will be presented in chronological order, not to make a historical construction. Rather, this order may show some unchanged rules through decades. Therefore, these examples will be analyzed on the basis of the spatial order that is influenced by materiality of glass.

IV. FUNCTION OF ALGAE FAÇADES

Most of the current energy is dependent on fossil energy these days that is impossible for recycling and has disadvantages of causing environmental pollution, and the world is facing energy problems due to the depletion of energy resources. Currently, there have been various attempts and new trials for energy renewal technologies replaceable for fossil energy sources. Buildings also have given a lot of influences on the energy issue; actually, 40% of the energy consumption of the entire Earth and 35 percent of carbon dioxide emissions has occurred from the buildings.

Building owners or residents have concerns to strive for energy-saving and environmental conservation by utilizing with eco-friendlier energy resources for their physical environment. In this paper, Algae Façade system is proposed as an energy-friendly building component to improve energy productivity and indoor environmental quality (IEQ), give flexibility elevation changes in aspects of the symbolism, and implement indoor settings and various spatial moods through the color effect of the building.

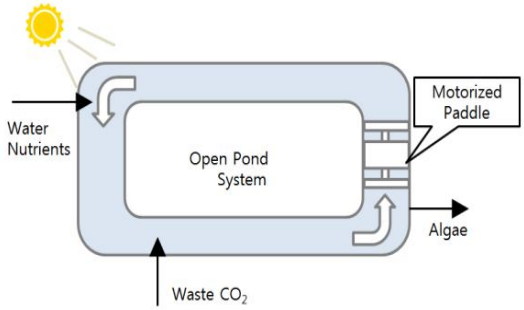
Algae cells are filled with oils into droplets that are regarded as promising rich resources. Since oils of algae cells can be converted into biodiesel and algae consume carbon dioxide (CO_2) during the culturing process, it is useful to use algae resources for improving the interior comfort with producing oxygen (O_2) by converting from CO_2. Algae resources can normally be classified into macroalgae and microalgae. Macroalgae are well known as seaweed having multicellular organs raised from the seawater, and comparatively, the freshwater algae grow up to 60 meters in a singular form. [12]

Microalgae has a unicellular organization and are grown normally in seawater. Freshwater environment make microalgae grow fast just in the same way by cell division as macroalgae, and provides much nutrition to have enough strength. Oil production of microalgae is at least 100 times greater than that of soybeans. Optimal culture conditions according to these microalgae species are varied, and they can be selectively cultured in accordance with the national weather. Consisting of particularly invisible microalgae is superior to be applied to the building and advantageous for visual aspects towards façade systems.

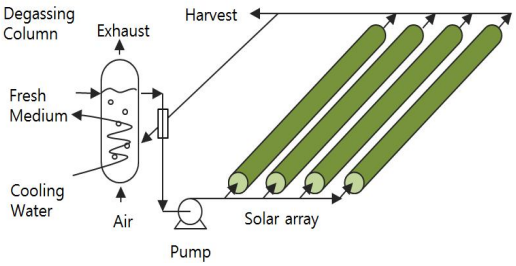
Algae fuel is somewhat unfamiliar concept comparison with among renewable energy, like a wind power, solar energy, geothermal energy, the principle is the method of producing biodiesel using a green algae. It is a method that combines the environment recovery features, such as absorbing carbon dioxide in the water and in the air and seawater eutrophic substance.Production of algae energy technologies are largely divided into two methods, the first is open pond system and the second is a close photobiological effector system. [12]

First, open pound system, while culturing the green laver large pond supplied with sunlight and CO_2, a method of producing energy. In order to facilitate the supply of light, and it requires a large area.Order to be configured in the outer space on a large scale to produce energy in the form of a farm, there is a cheap

advantage operational costs, but there is the difficulty of water loss due to evaporation and the CO_2 supply. On the other hand, Closed photobiological effector system, in a method for culturing microalgae in a glass tube, is no contamination from external and water evaporation compared to open pond system, and shows a 30-fold efficiency. [13]



(a) Open Pond System



(b) Closed Effector system

Figure 2. Conceptual Diagram of Algae Cultivation System (Source: Kim and Han, 2016)

Judging on this basis, close photobiological effector system can be said appropriate as method to apply algae to the building. [14] Furthermore, it is judged that using the whole surface of windows and doors instead of conduit of pipe shape as lane form to actively transform water with high specific heat to building energy upon usage in the building would make better efficiency.

Figure 3. Case Model for Algae Façade (Source: International Building Exhibition)

V. PROPOSAL FOR INTEGRATIVE DESIGN WITH ALGAE FAÇADES TOWARDS GLASS ENCLOSURES

Configuring the method of the convergence technology based on the strengths and potentials shown by the analysis is as the following; first, the method for producing energy using microalgae is applied to closed photobioreactor system, and they are cultivated in plate-shaped glass windows or glass walls rather than culturing in the transparent conduit; second, it has initially been constituted by the experimental standard mock-up unit, because the container unit has many specifications and combination methods. Also, the standard wall configuration isas shown on Figure 4.

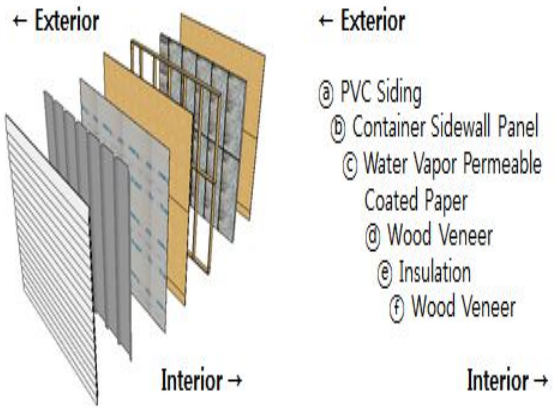


Figure 4. Experimental Configuration of Algal Façade (Source: Park and Han, 2016)

By applying the LED lamps in this system, building colors shows into a variety of building elevations. Buildings color is one of major factors that affect human senses and the environment as well, has excellent strength of the stimulus than the shape and material, and has the influence to determine the image of the building. In addition, it makes the image and atmosphere of the city varied infinitely. Impacts of building colors also tend to be dependent on the situation and location such as country or region, and so, it is difficult to make a precise definition of color. Even if only 5% of different colors used for building surfaces with the same mass form makes a feeling that buildings are different. Interior building spaces can also be varied and differentiated via a different set of colors.

The color of the seaweed is ranged about the saturation green. Colors with low saturation are often used for making dark images and not suitable for buildings. Low-saturated colors of the entire monochromatic settings of the building change the surrounding environment to boring or dark atmosphere, and such a problem can be resolved through the artificial light LED lamps to change the color from the algae; the building will change colors in multiple ways under the influence of daylight. The brightness by temporal variations to receive the direct sunlight can be changed actively and displayed vividly. And the degree of the change also varies depending on materials of the building façade. In addition, Algae Façade should have light-shielding properties by the color images and be applied in consideration of the characteristics of the exterior materials of the building. [15]

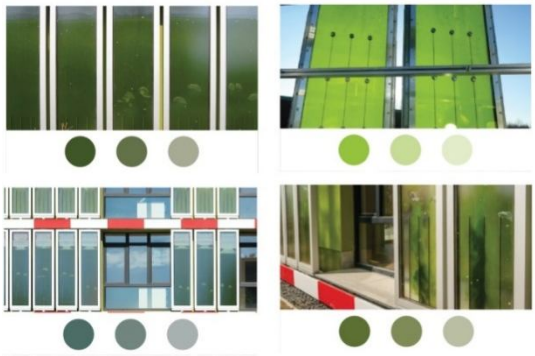


Figure 5.Color Changes for Algal Glass Enclosures (Source: Jo and Han, 2016)

After combining the LED lamps with a transparent system of dopant, closed photobioreactor system may innovatively turn into new platform to support for both algae cultivation and color representation. Algae growth can be sustained through the LED lamps after all, and for example, a LED lamp making blue light may affect the reproduction of the plants and red lights able to affect the nutritional growth. Microalgae stay as a transparent plate to pass the natural light during the day, and carry out photosynthesis through the LED lamp at night. Also, LED lamps give aesthetic changes of the building mass by various color representations.

Figure 6.Example for Algal Glass Façade (Source: IBA-Hamburg)

CONCLUSION

This study presents an examination of the examples of most influential tendency of glass buildings, with the perspective of architectural type. Defining the glass buildings as an architectural type and investigating prototypical rules of spatial organization in seminal examples enable to recognize what is lied in the building images. Rather, the root order of glass buildings seems to be evolved through new possibilities of steel-and-glass construction.

In this paper, it made a continuous development of alternative energy due to energy resource depletion and environmental degradation, and to apply the environmentally friendly energy generation in the construction sector and want to present a new application systems for energy efficiency and building envelope. To ensure the comfort of the energy performance and environment via algae, the proposed façade system is expected to be useful for human health and natural environment as well.

Also, LED lamps give aesthetic changes of the building mass by various color representations. Development of the LED lamp system in a uniformed shape to cultivate algae without affection by the natural environment is continuously performed as an ongoing project. The proposed system is expected to be applied not only a new construction and any existing buildings as well, and it will cover from the environmentally friendly energy generation in the field of AEC (architecture, Engineering and Construction) to a new application system for increasing energy efficiency and the beauty of building envelopes.

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